Developing a Constant Model of Thickness Variation for Composite Materials

Gregory Teitelbaum
Havre de Grace High School
August 15, 2003
Army Research Laboratory-WMRD
Dr. Shawn M. Walsh

X____

Abstract

This report documents the research conducted in order to develop a standard model for the infusion of a composite material panel. Equipment was used to measure and document the thickness variation during infusion. A graphical pattern was designed and a standard "thickness change vs. time" graph was developed.

Introduction

Composite materials, non-metallic, high-performance plastics reinforced with fibrous materials, are becoming some of the most viable options for manufacturing that requires lightweight yet durable materials. They are currently serving as a solution to weight problems in many current applications. Today, composite materials are used in everything from large boat hulls to the thinnest of fishing rods. One current application undergoing development is the use of composite materials in armor. The United States Army is currently funding a program known as the Future Combat Systems (FCS). This program calls for the quick deployment of lighter and more lethal weapons systems. A possible way in which the Army looks to solve this problem is to create lightweight tanks using a composite armor. In order to process this armor with acceptable strength properties while maintaining cost-effectiveness, the method must be standardized.

Body

The development of composite materials currently falls into three categories. Autoclaving, the oldest of the three, involves placing the part into a heated pressure vessel to infuse the fiber with a resin and then cure it. This is an expensive process due to the large initial capital investment of purchasing an autoclave. Resin Transfer Molding (RTM) involves using a large press to force the resin into the fiber portion of the composite. The most recent of these three technologies is Vacuum Assisted Resin Transfer Molding (VARTM). During a VARTM infusion, a vacuum is placed on the part, therefore “pulling” the resin through the part and distributing it evenly. As VARTM is currently the most practical application because of low cost and simplicity, it is being used to test the developments of a composite armor.

One of the most popular VARTM infusion methods is the Seemann Composite Resin Infusion Molding Process (SCRIMP). This method involves using a thin distribution medium in direct contact with the part to spread resin flow quickly on the surface of the part. After the part is infused and cured, this layer is then removed and disposed. This method was used in the armor manufacturing process because of its widespread use in the industry.

The change in thickness during infusion was measured through a machine known as the Linear Variable Differential Transducer (LVDT) (Figure 1). Using a selected number of transducers, different points of the part are measured

Figure 1- LVDT over a composite Panel

simultaneously as the part is infused. The transducers consist of a metal hollow tube passing through a second hollow tube. The magnetic resistance reads an exact value as the inner tube moves within the outer tube. This resistance can be calculated as an exact measurement accurate to better than one thousandth of an inch. This accuracy is necessary when the change in thickness is very small.

An initiative was taken to find a constant and standard graph for the change in thickness vs. time of a composite panel. Two types of panels with a similar setup were chosen. The standard setup for the panels in the experiment was a backing plate of 11 plies of IM-7 graphite with 24 plies of S-2 woven glass on top. One type of panel was constructed through a hand lay-up ply by ply. A company called Solectria provided the second type of preform. In this panel, all 35 plies of fabric were pre-binded with a small amount of binder. Therefore, these panels were already somewhat compacted before infusion. Eleven panels were compiled for this set of experiments, six of which were hand-assembled and five binded preforms provided by Solectria.

Each panel was placed under a vacuum of 30 inHg with a feed line at one end and a vacuum line at the other (Figure 2). The LVDT was placed over the panel with 12 transducers to measure the thickness simultaneously, excluding the last three, which had nine transducers. These transducers were arranged on rows of three, starting after the feed line (where the resin enters the panel) and ending before the vacuum line (where the vacuum is pulled).

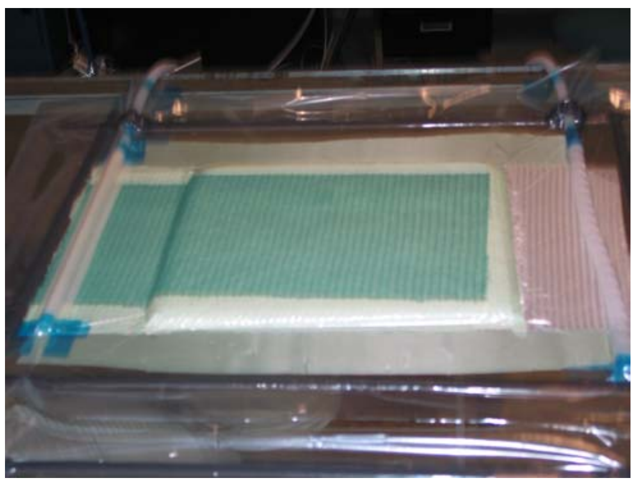

Figure 2- Standard SCRIMP setup with 24 plies S-2 Glass and 11 plies IM-7 graphite.

The first panel tested was a non-binded preform. As this was the first in a series of experiments, many steps were conducted incorrectly. First, the bagging was faulty and the part filled inconsistently, as can be seen in the results

(Appendix 1). The resin feed was also terminated prematurely, causing a dip in the thickness from 2700-3500 seconds, when the resin was reintroduced to the part. Because of the incorrect procedure, this panel was a failure and this graph was considered an outlier.

Panel two was also a non-binded preform. This graph depicts a much different pattern. The panel increased in thickness overall and also was very sharp in its increasing and decreasing slopes (Appendix 2). This was attributed to what is known as race tracking. The resin flow will follow the path of least resistance, and in this case, because there was a gap between the preform and the vacuum bag, the resin flowed around the part instead of through he part. A dry spot at the bottom of his panel proved this theory and determined panel two as yet another outlier in the series of graphs.

The third panel was yet again a hand assembled preform without a binder. The thickness of the part slowly increased until about the 1500 seconds, where it began to increase greatly (Appendix 3). Once the resin feed was clamped off, the thickness never decreased and stayed at a much higher level. Because of the fact that this panel increased in thickness at almost five times the expected level, this panel joined the list of possible failures.

The fourth panel was the first of the binded Solectria preforms that were used in this set of experiments. With this panel, we saw the first of successful results. The panel increased in a nice exponential curve, and then began to taper off after the resin feel was cut off. The lone problem with this experiment was that air made it into the part, causing air bubbles to race around the sides. (Figure 3) These bubbles caused the fluctuations that can be seen in the change in thickness vs. time graph (Appendix 4). Despite the one problem, this provided the first of the results that the standard model would be based upon.

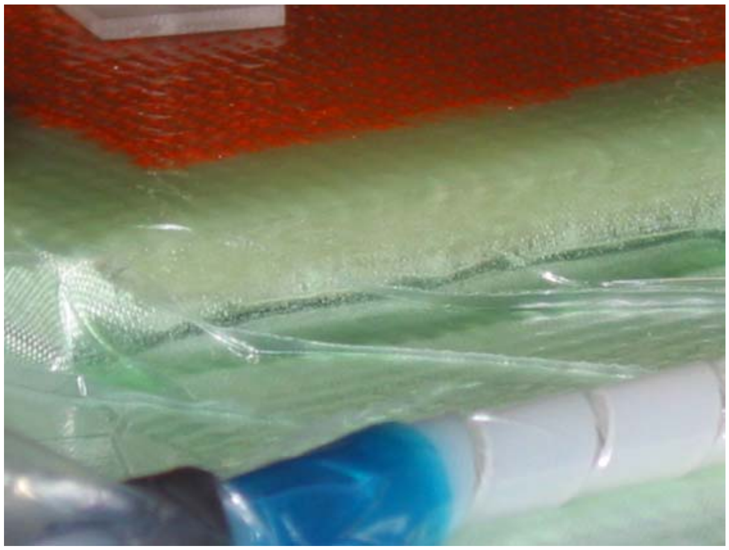

Figure 3-Air bubbles along the edge of a panel.

With the fifth panel, the experiments returned to the non-binded preforms. This panel began with a slight dip for a few seconds before an increase was seen in the change in thickness vs. time graph (Appendix 5). This was consistent with the first successful results in panel four. Again, air bubbles made it into the bagging and the fluctuations were still seen in the graph. Regardless of this one problem, this was again a large step towards a successful model.

The sixth panel was yet again a hand-laid preform. This experiment started off very well, with the same increase seen in the last two panels (Appendix 6). For an undetermined reason, at around 3200 seconds, some but not all of the sensors dropped dramatically. The best hypothesis for which this happened is that the panel was bumped during the infusion, knocking some of the transducers out of place. With the results from panel six, more good data from the beginning of an infusion was collected.

Panel seven, a non-binded preform, was the first unconditional success. The change in thickness increased on the same pattern as suspected, and tapered off as should be (Appendix 7). There was no leak in the bag; therefore there were no fluctuations in the data. This was a strong example of what the standard model should look like.

Panel eight was a Solectria preform that did not perform as expected. In this experiment, all but the first set of transducers acted inconsistently, increasing slower and less overall (Appendix 8). The first set of transducers provided useful information, so this was yet again a helpful panel in the set of experiments.

The ninth panel, provided by Solectria, was one of the most successful of all of the panels. The results were impeccable and the change in thickness vs. time graph was exactly how it was hypothesized (Appendix 9). This was a panel that provided much information for the final standard model.

Solectria again provided a binded preform for the tenth panel. This experiment provided the best data of all eleven panels. It was very similar to the previous panel, only the transducers were slightly more uniform (Appendix 10).

Again, this was a very successful panel that was helpful in the final standard model of the change in thickness vs. time graph.

The last and eleventh panel was a Solectria preform. The results were again constant to what had been seen, only air had leaked into the bag and had caused more fluctuations in the data (Appendix 11). With all of the experiments completed, the standard model for thickness variation was ready to be constructed.

In order to develop the standard model, the average final thickness change was first calculated. On average, the average thickness change was around .04 inches. Next to be determined was the constant pattern that the graph followed. It was determined that the graphs usually dipped slightly for a short period (100 seconds) then increased exponentially until the resin feed was clamped (3000 seconds). At this point, the graphs usually tapered off and leveled out by 12000 seconds. With this information, the standard model for thickness variation was created (Appendix 12).

Conclusions

With the designed experiments and the calculated data, an effective standard model for the change of thickness vs. time graph for composite materials was created. This is an effective and accurate tool that can be used to determine the quality of the parts produced based on the graphs that they provide. Finally, this model is crucial in creating a reliable system for a VARTM process so that an effective method for the production of the complex structures can be developed.

Acknowledgements

The author thankfully acknowledges the contributions and assistance from the following: Dr. Melquiades Allende, Dr. James Campbell, Mr. John Cook, Mr. David Crosland, Mr. Clinton Isaac, Mr. James Keithley, Mr. Nicholas Kurlick, Dr. Kirk Tackitt, and Dr. Shawn Walsh, all of the Army Research Laboratory.

Bibliography

1. Shawn M. Walsh, Elias J. Rigas, William A. Spurgeon, Walter N. Roy, "A Non-Contact Distribution Scheme for Promoting and Controlling Resin Flow for VARTM Processes", December 2000.

2. Shawn M. Walsh, Elias J. Rigas, Melquiades Allende, and Kirk Tackitt, "Minimizing Cycle Time and Part Mark-Off in the FASTRAC Process", November 2001.

3. Shawn M. Walsh, “Manufacturing Challenges and Opportunities for the Future Combat Systems”, August 2002.